LCA Case Studies

Environmental Systems Analysis of Pig Production

The Impact of Feed Choice

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Abstract

Goal, Scope and Method. The purpose of this environmental system analysis was to investigate the impact of feed choice in three pig production scenarios using substance flow models complemented by life cycle assessment methodology. The function of the system studied was to grow piglets of 29 kg to finished pigs of 115 kg. Three alternative scenarios of protein supply were designed, one based on imported soybean meal (scenario SOY); one based on locally grown peas and rapeseed cake (scenario PEA) and one based on Swedish peas and rapeseed meal complemented by synthetic amino acids (scenario SAA). The environmental impact of both feed production as such and the subsequent environmental impact of the feed in the pig production sub-system were analysed. The analysed feed ingredients were barley, wheat, peas, rapeseed meal, rapeseed cake, soybean meal and synthetic amino acids. The crude protein level of the feed affected the nitrogen content in the manure, which in turn affected nitrogen emissions throughout the system and the fertilising value of the manure, ultimately affecting the need for mineral fertiliser application for feed production.

Results and Discussion. The results showed that feed production contributed more than animal husbandry to the environmental burden of the system for the impact categories energy use, global warming potential and eutrophication, whereas the opposite situation was the case for acidification. The environmental impacts of scenarios SOY, PEA and SAA were 6.8, 5.3 and 6.3 MJ/kg pig growth; 1.5, 1.3 and 1.4 kg CO_2-eq/kg pig growth; 0.55, 0.55 and 0.45 kg O_2-eq/kg pig growth; and 24, 25 and 20 g SO_2-eq/kg pig growth, respectively. The results suggested that scenario SAA was environmentally preferable, and that the reason for this was a low crude protein level of the feed and exclusion of soybean meal from the feed.

Conclusions. Feed choice had an impact on the environmental performance of pig meat production, not only via the features of the feed as fed to the pigs, such as the crude protein content, but also via the raw materials used, since the environmental impact from the production of these differs and since feed production had a large impact on the system as a whole.

Keywords: Crude protein; feed production; growing-finishing pigs; pig production; soybean meal; synthetic amino acids; systems analysis

Introduction

Pig meat is the most common type of meat consumed in Sweden, amounting to 36 kg pig meat per person and year (SBA 2002a). Most pig meat consumed in Sweden is produced within the country; and the production corresponds to 3.2 million pigs per year (SBA 2001a, SBA 2002b). Conventional Swedish pig production can briefly be described as consisting of two consecutive phases: rearing of sows that produce piglets and growing of piglets to produce slaughter pigs for the meat industry.

The present production of Swedish pig meat gives rise to an environmental impact in terms of energy use, eutrophication of waters, contribution to global warming and acidification, ecological toxification by use of pesticides, soil erosion and loss of biological diversity (Cederberg and Darelius 2001). In order to facilitate the development towards a more sustainable production, there is a need to analyse the potential for improvement in the system. Agricultural production, in contrast to slaughter, retail processes, etc., is for many impact categories the most important phase during production of pig meat (Cederberg 2003). Feed production and animal husbandry can be identified as the two major subsystems within the system of agricultural pig production.

The possibility of reducing the environmental impact of pig production has been studied by other authors. Backus et al. (1998) focused on mineral excretion and concluded that both management measures, such as low emission housing systems, and reducing the mineral content in the feed ration, can contribute to reduced mineral excretion. Canh (1998) studied the effect of dietary composition on ammonia emissions from growing-finishing pigs, and similarly concluded that ammonia emissions can either be controlled by management techniques or by feed intake including dietary composition, which in turn determines the amount and form of excreted nitrogen. Williams (1995) also studied mineral excretion, and found that nitrogen and phosphorous in animal excreta are two of the main sources of pollution of agricultural origin. Williams states further that feeding systems that accurately supply the nutritional needs of pigs at different stages of growth (e.g. multi-phase feeding), the use of feed additives that contribute to improved feed utilisation, and increased growth rate (e.g. via genetically improved livestock) all reduce the excretion of nitrogen and phosphorus. A number of other authors have likewise scrutinised how

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dietary manipulation can reduce mineral excretion from pigs: Lenis (1989), Fullarton and Cullin (1992), Jongbloed and Lenis (1992), Cromwell et al. (1996) and Henry (1996). In addition to investigating improvement of digestibility and utilisation of nitrogen and phosphorous by pigs, Jongbloed and Lenis (1992) also discuss the fact that a use of by-products and waste products from the food processing industries as feed enhances the national mineral balance, in spite of contributing to a higher excretion from the pigs.

Environmental impacts relating to Swedish pig production have been studied by Cederberg and Darelius (2001). The system studied included both piglet production and production of growing-finishing pigs in south-western Sweden. The authors conclude that it is of vital importance to have an efficient nitrogen utilisation throughout the life cycle of pig meat production. A high nitrogen efficiency not only minimises direct and indirect emissions of nitrogen compounds to air and water, but is also a key factor for a reduced use of fossil fuels. This was explained by the energy-intensive production of synthetic fertilisers, which constituted a large share of the total energy use. Their results showed that energy use, use of resources, and contribution to global warming and eutrophication, were higher for feed production than for pig husbandry.

On the other hand, the pig sub-system had a higher influence on contribution to acidification and photochemical oxidant formation. Kumm (2003) made a systems study of nitrogen pollution from Swedish pork production including feed production, animal feed conversion, manure management and spatial location of pig farms. The author suggests that improved animal protein conversion and suitable spatial location of pig production are more cost-effective for nitrogen reduction than measures in feed production and manure handling.

The feeding plans for conventional growing-finishing pigs usually include cereals to fulfil the energy requirements of the animals and soybean meal and rapeseed meal to fulfil the need for protein. The use of soymeal for pig feed has more than doubled since the beginning of the 1990s (Statistics Sweden 1996, 2003). In an environmental assessment of agricultural land use, production of soybean, rapeseed and oil palm was compared. The production of soybean in Brazil caused a higher loss of biodiversity through its devastation of natural habitats, caused more soil erosion and had a more extensive use of pesticides than rapeseed production (Mattsson et al. 2000). There are thus a number of environmental reasons to avoid the use of soybean in animal feed.

1 Goal and Scope

This study addresses two of the main environmental problems of pig production: Nitrogen emissions from animal excreta; and problems associated with the use of soybean. As the nitrogen emissions to a large extent are connected to intake of crude protein, both problems are closely related to choice of feed. The purpose of this study was to investigate the impact of feed choice on the environmental performance of growing-finishing pig production. The emphasis was placed on quantification and comparison of environmental impacts from feed production and pig rearing, related to different feeding strategies. The environmental impact categories considered were resource use in the form of primary energy use, potential contribution to global warming (GWP), acidification and eutrophication. To achieve the purpose of the study, some sub-targets were defined: 1) to quantify the environmental impacts from three different scenarios; 2) to highlight the parts of the production chains that dominate the different environmental impact categories, i.e. to find the 'hot spots' of the systems; and 3) to rank the scenarios according to environmental performance for each impact category.

A way to reduce the intake of crude protein is to use synthetic amino acids. These can give the feed a better amino acid balance, and thus avoid overfeeding with unnecessary protein. In an attempt to find an improved feeding strategy we formulated a domestic feed that both excluded soybean products and had a low crude protein level (scenario SAA). The environmental impact from this scenario was then compared to that of two other. One scenario extrapolated the present trend of increasing soybean use (scenario SOY), and because this scenario was closest to current praxis it was used as a reference case in this study. The other scenario used organic pig feed as a role model (scenario PEA). In organic pig production, chemically extracted protein feeds (such as rapeseed meal) and synthetic amino acids are not allowed (IFOAM 2002). The three scenarios of feed choice were selected with the purpose of reflecting the effect of different feedstuffs and different crude protein levels, and are described in **Table 1**.

The selected pig production system was for the fattening of growing-finishing pigs.

Production of piglets and a corresponding share of the sow were not studied since inclusion of these would not significantly increase the comprehension of the impact of feed choice, as they were assumed to respond in a similar way to crude protein intake.

Table 1: Diet composition [% of weight] and feed characteristics of the three scenarios in the study[a]

Scenario	SOY	PEA	SAA
Barley (10%; 12 MJ)	44.5	62.8	40.7
Wheat (12%; 14 MJ)	40.0	–	40.0
Pea (23%; 13 MJ)	–	21.0	8.5
Rapeseed cake (33%; 14 MJ)	–	12.7	–
Rapeseed meal (36%; 11 MJ)	–	–	7.0
Soybean meal (44%; 13 MJ)	11.9	–	–
Synthetic lysine	0.11	–	0.20
Synthetic threonine	–	–	0.05
Vitamins and minerals, etc	3.5	3.5	3.5
CP content[b][g/kg feed]	147	155	137
ME content[b][MJ/kg feed]	12.5	12.2	12.4

[a] The diets were composed to meet amino acid requirements according to NRC (1998). Feed contents from NRC (1998), Simonsson (1995)

[b] CP=crude protein, ME=metabolisable energy; (CP; ME)

2 Functional Unit

The function of the studied system was to produce slaughter pigs ready for delivery at the farm gate. The functional unit (fu) was defined as 1 kg pig growth, being an average kg of growth taking place in the interval of 29–115 kg. The different pig diets were assumed not to influence the meat quality from a consumer perspective (Anders Högberg, pers. comm.).

3 System Description

The study included processes at a mixed arable-livestock farm, where both pig fattening and production of feed ingredients took place. Production of soybean meal, rapeseed meal and synthetic amino acids was also included in the study, as was upstream production of mineral fertiliser, seed, diesel, fuel oil and electricity. Production of other feed additives such as premix, mono-calcium-phosphate and salt was not studied, since these products were added to the same extent (3.5%) in all scenarios, and were furthermore assumed to not markedly influence the final result. Since the focus was on feed choice, processes not related to this were also omitted. Some examples of these are production of buildings, machinery, infrastructure and veterinary medicines. A more detailed description of the feed production system and the pig production system can be found in the section on model description. The processes included in this study are shown in **Fig. 1**.

4 Methods

The methodological approach of this environmental systems analysis was to utilise substance flow models complemented by life cycle assessment (LCA) methodology. The substance flow models were developed as part of the research project and are named SALSA-arable (Elmquist et al. 2004) and SALSA-pig; SALSA stands for Systems Analysis for Sustainable Agriculture. The SALSA-pig model is intended to be used in combination with SALSA-arable in order to analyse an entire system of production of growing-finishing pigs. The models are briefly described in Sections 4.1 and 4.2 below. LCA methodology was used to set the scope of the models and to interpret the simulation results in terms of potential environmental impact (ISO 1997). As part of the inventory analysis, the physical flows of three different scenarios of pig production were simulated in the SALSA models. Thereafter, the resulting parameters (energy use, NO_3^-, N_2O, NH_3, NO_x, SO_x, P, CO_2 and CH_4) were used in the impact assessment phase of the study.

4.1 Model description: SALSA-arable

Energy use and emissions of relevance for the chosen impact categories from production of the locally grown feed ingredients (winter wheat, barley, peas and rapeseed) were quantified in the SALSA-arable model. The model used 22 emission points to describe the system, including: Field operations, soil, plant, indirect nitrous oxide, drying, pressing of rapeseed oil, diesel production, mineral fertiliser production, and seed production. Data on field operations and soil type (clay) were taken from a farm in the county of Stockholm (Lars Törner, pers. comm.); the emissions derived from tractor driving were taken from Hansson and Mattsson (1999) and Uppenberg et al. (2001). Data on mineral fertiliser production were taken from Davis and Haglund (1999). Leaching was calculated as for Svealand region according to Hoffman et al. (1999); the model takes into consideration leaching specified to geographic location, manure application, tillage time, crop type and fertiliser level relative to crop uptake. Direct and indirect emissions of nitrous oxide deriving from fertiliser nitrogen input to soil and from nitrogen emissions, respectively, were calculated according to IPCC (2001a). A list of the input materials used for each crop is presented in **Table 2**.

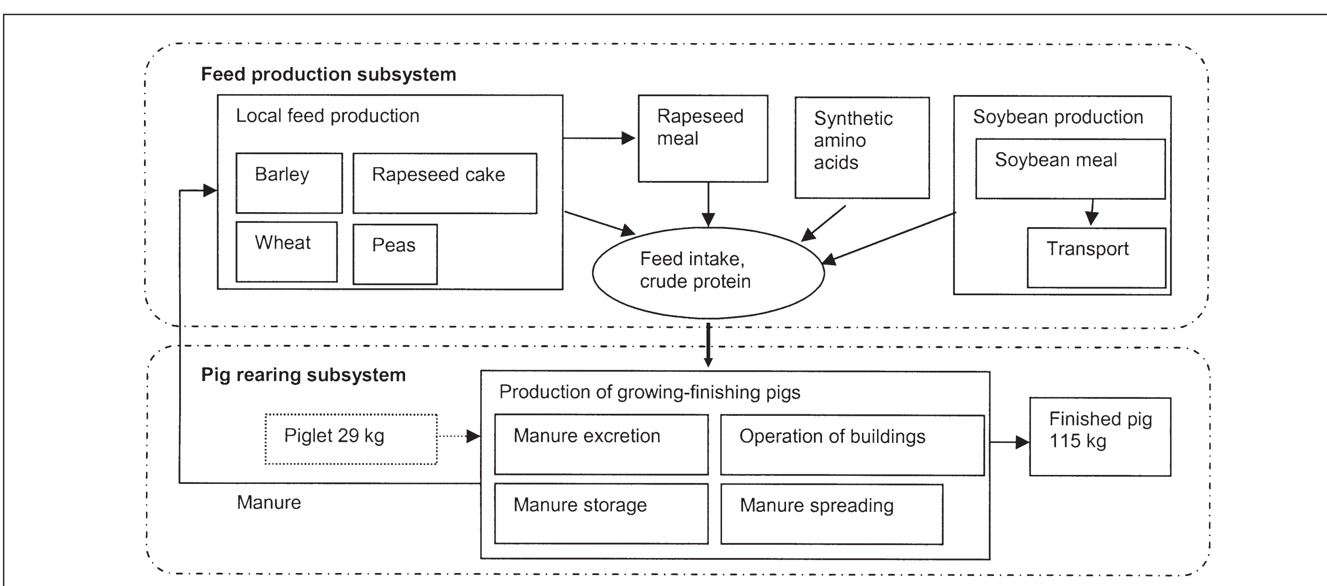


Fig. 1: The pig production system studied included production of feed ingredients and processes involved in production of growing-finishing pigs. The functional unit of the study was 1 average kg pig growth between 29 kg to 115 kg

Table 2: Data on input materials and direct energy use for agricultural production and for extraction

Crop	Unit	Barley	Peas	Rapeseed for cake	Rapeseed for meal	Soybean	Wheat
Seed[a]	kg/ha	185	250	10	10	50	220
Diesel – tractor operations[b]	litre/ha	90	77	94	94	60	80
Drying[c] – heat[d]	MJ/ha	950	550	450	450	910	1300
Drying[c] – electricity[e]	MJ/ha	150	85	70	70	120	200
Extraction[f] – heat[g]	MJ/ha	–	–	–	1360	2140	–
Extraction[f] – electricity[e]	MJ/ha	–	–	610	200	360	–

[a] Agriwise 2002 (barley, peas, rapeseed, wheat); Agbrazil 2002 (soybean)
[b] Törner, pers. comm. (barley, peas, rapeseed, wheat); Cederberg and Darelius 2001 (soybean)
[c] Elfversson pers. comm. (barley, peas, rapeseed, wheat); Cederberg and Darelius 2001 (soybean)
[d] Fuel oil (barley, peas, rapeseed, wheat); biofuel (soybean)
[e] Swedish average electricity (barley, peas, rapeseed, wheat); hydro power (soybean)
[f] Cederberg 1998, Hovelius 1999 (rapeseed meal); Bernesson et al. 2004 (rapeseed cake); Cederberg and Darelius 2001 (soymeal)
[g] Liquefied petroleum gas (rapeseed meal); biofuel (soybean)

A summary of the calculated mineral fertiliser use and the other nitrogen sources in the scenarios is found in **Table 3**. The rate of manure application in each scenario was calculated by dividing the nitrogen content in the manure from one pig by the sum of the acreage of winter wheat, barley and rapeseed (=the spreading area) in each scenario. The amount of crop-available N in the manure was set to 100% of the ammonium-nitrogen content, after losses occurring in the barn, manure storage and field (SBA 2001b). These emissions were attributed to the animal sub-system.

Data on production of soybean and the subsequent extraction and distribution of soymeal were taken from a Brazilian farm described in Cederberg and Darelius (2001). These input data were used in an auxiliary model, which described the system in twelve sub-models: diesel combustion at the farm, fertiliser production, seed production, drying of seeds, soil and crop, indirect nitrous oxide generation, transport from farm to extraction plant, extraction, transport from extraction plant to harbour, ocean transport from Brazil to Germany, sea transport from Germany to Sweden and transport from Swedish harbour to farm. The model used data from the database NTMcalc (NTM 2002) for calculations of transport activities.

Since both soybean and rapeseed give rise to more than one product, the impacts from rapeseed production and soybean production were allocated to the two co-products oil and expeller, to reflect the economic driving force behind the production. The factors used for allocation are listed in **Table 4**. Rapeseed cake and rapeseed meal are two slightly different

Table 3: Recommended nitrogen rates, supply from different sources and nitrogen leaching for different crops (kg N/ha)

Crop	Barley	Peas	Rapeseed	Soybean	Wheat
Yield [humidity level in %][a]	4100 [15%]	2400 [15%]	1700 [9%]	2200	5700 [15%]
Nitrogen rate (N-rate)[b]	68	–	76	–	103
Nitrogen supply from…					
…nitrogen fixation (N-fix)[c]	–	76	–	118	–
…short-term slurry effect (N-short)[d]	42/45/35	–	42/45/35	–	42/45/35
…long-term slurry effect (N-long)[b]	10	10	10	–	10
…preceding crop effect (N-pre)[b,e]	–	30	15	30	–
…calculated mineral fertiliser use (N-min)[f]	16/13/23	–30	9/6/16	–30	51/48/58
Nitrogen leaching[g]	13	14	15	40	19

[a] Statistics Sweden 2002a; 2002b (barley, rapeseed, wheat; peas); Cederberg and Darelius 2001 (soybean), humidity not specified
[b] According to recommendations of the Swedish Board of Agriculture (SBA 2001b)
[c] Calculated as nitrogen content in seeds (Högh-Jensen et al. 1998)
[d] From SALSA-pig, scenario SOY/PEA/SAA, respectively
[e] Accounted as an avoided use of mineral fertiliser, soybean was assumed to have the same effect as peas
f N-min was calculated for scenario SOY/PEA/SAA, as N-rate minus (N-short + N-long + N-pre), for peas and soybean only N-pre
[g] According to Hoffman et al. (1999) except for soybean, taken from Cederberg and Darelius 2001

Table 4: Allocation between oil and meal or cake

Product	Scenario	Mass%[a]	Production kg/ha	Price[b] US-$/ton	Share of income[c]
Soybean oil	SOY	17	374	592	0.31
Soybean meal	SOY	80	1760	284	0.69
Rapeseed oil – small-scale	PEA	31	527	n.a.	0.70[d]
Rapecake – small-scale	PEA	66	1123	n.a.	0.30[d]
Rapeseed oil – large-scale	SAA	44	748	619	0.70
Rapemeal – large-scale	SAA	54	919	221	0.30

n.a. = not available
[a] Extraction rates from Cederberg 1998 (soy products) and Bernesson et al. 2004 (rapeseed products)
[b] Lowest asking prices for the nearest forward shipment, Oil World Monthly 48: 46, 2003
[c] The share of income was used as a basis for allocation procedures (=economic allocation)
[d] Small-scale rapeseed products were assumed to have the same allocation factors as large-scale rapeseed products, as the lower feed value of cake compared to meal was assumed to be compensated for from an allocation perspective by the larger production volume

products. Rapeseed meal is based on the expeller from industrial pressing of rapeseed, which is then processed further by solvent extraction to gain more oil. Rapeseed cake is the expeller left after small-scale pressing of rapeseed at the farm, and thus contains relatively more fat and less protein than the rapeseed meal.

Data on production of synthetic amino acids were taken from an LCA report on methionine in poultry production (IFEU 2002). Synthetic lysine and threonine were assumed to have the same impact per kg product as methionine.

4.2 Model description: SALSA-pig

The SALSA-pig model was used to calculate the feed intake for one growing-finishing pig, as well as to quantify the energy use and emissions from pig farming processes. Included processes of SALSA-pig were: operation of buildings, manure excretion, manure storage, manure spreading, tractor emissions from manure spreading and indirect emissions of nitrous oxide. Data on quantity and nitrogen content of pig manure produced were generated in the SALSA-pig model and transferred to the SALSA-arable model, which adjusted the rate of mineral fertiliser according to the nitrogen content of the manure. Some of the model outputs are listed in **Table 5**.

The feed consumption sub-model calculated the amount of feed, for each diet studied, that was needed to fulfil the metabolisable energy (ME) requirements for one pig when growing a set growth interval. The mean ME requirement per kg growth was set at 35 MJ.

The manure excretion sub-model calculated the amount of manure produced, nitrogen excretion and the emissions occurring indoors from one pig. The housing system was assumed to be pens with one third slatted floor and daily manure removal. The manure production was calculated as 0.55 kg faeces and 1.6 kg urine per kg consumed feed; water was given ad libitum (SBA 2001c). Waste water (216 kg), waste straw (7 kg) and urine production due to straw intake (27 kg) to a total of 250 kg per pig were added to the weight of the final manure. The dry matter content (DM) of the manure was calculated as the sum of the DM content in urine and faeces, 2% and 30% of the weight, respectively.

The ammonia emissions in the barn were related, in a second order relationship, to the amount of nitrogen excreted, which in turn was dependent on nitrogen intake derived from the protein of the diet. A conversion factor of 0.158 kg nitrogen per kg protein intake was used. The relationship between nitrogen intake and nitrogen excretion was taken from a Dutch study (Canh et al. 1998), from which a linear trend was estimated (**Eq. 1**). This equation was used to calculate the nitrogen excretion, N_{ex} (kg per pig) in the manure excretion sub-model.

$$N_{ex} = (0.89 \times N_{in}) - 1.70 \qquad (1)$$

where N_{in} is the nitrogen intake in kg per pig.

The dependence of ammonium nitrogen (NH_3-N) volatilisation on nitrogen content in the excreted manure was also taken from Canh et al. (1998). However, the absolute level of the emission was calibrated to the Swedish conditions of more frequent manure removals by setting a reference point of 14% lost NH_3-N (instead of 20%) at 3.6 kg nitrogen excreted per pig (Steineck et al. 2000). The emission function (EF) formed in this way is presented in **Eq. 2a**. The NH_3-N losses, N_{em} (kg per pig) in the barn were then calculated by multiplying N_{ex} by the EF (**Eq. 2b**). The value of the emission function was 13.0% for scenario SOY; 14.3% for PEA; and 12.0% for SAA.

$$EF = (0.033 \times N_{ex}) + 0.022 \qquad (2a)$$

$$N_{em} = N_{ex} \times EF \qquad (2b)$$

Data on emissions of methane were taken from IPCC (1996), where the feed energy intake in MJ is multiplied by a 0.6% enteric fermentation factor and a methane formation factor of 0.018 kg CH_4/MJ. No nitrous oxide was assumed to be formed from enteric processes.

The manure storage, sub-model calculated emissions from manure storage, assuming the storage was covered with a natural crust and that manure was filled from the bottom.

The ammonium-nitrogen emission factor corresponding to these settings was 4% of the incoming total nitrogen, where the latter was obtained by subtracting losses in the barn from excreted nitrogen (Karlsson and Rodhe 2002). The methane emission, CH_4 (kg per pig), from manure storage was calculated according to IPCC (2001a) as in **Eq. 3**.

$$CH_4 = VS \times DM \times B_0 \times d \times MCF \qquad (3)$$

where the amount of volatile solids, VS, in the manure was estimated at 0.87 (kg per kg DM), according to Dustan (2002). The dry matter content, DM, of the manure (kg per kg manure) was obtained from calculations in the manure excretion sub-model. The B_0 index (m^3 per kg VS) refers to the maximal potential biological CH_4 production of an analysed substrate, and is set at 0.45 for liquid pig manure according to IPCC (2001a). The density, d, of methane used in the model was 0.67 kg m^{-3}, and the methane conversion factor, MCF, used was 10% (Dustan 2002). Emissions of nitrous oxide from manure storage were calculated as 0.001 kg N_2O-N per kg excreted nitrogen, as recommended by IPCC (2001a).

Table 5: Selected outputs from the SALSA-pig model for the three scenarios

Scenario	SOY	PEA	SAA
Feed intake [kg per fu] [a]	2.80	2.86	2.82
Nitrogen excretion [kg per fu]	0.038	0.043	0.035
Slurry production, including waste water [kg per fu]	9.1	9.2	9.1
Dry matter content of slurry [%]	6.1	6.2	6.1
Ammonium nitrogen content of slurry after spreading [kg ton^{-1}]	2.3	2.6	2.0
Area for slurry spreading [m^2 per fu]	5.0	5.3	5.4
Slurry application rate [ton ha^{-1}]	18.2	17.4	16.9

[a] The feed intake was based on a requirement of 35 MJ ME/kg growth

The manure spreading sub-model calculated emissions from slurry application on the field. The emission factor used was 8% of the ammonium-nitrogen content of the slurry after storage. The spreading technique used was band spreading with soil incorporation within 4 hours (Karlsson and Rodhe 2002). For wheat, the slurry was spread in early autumn and in the spring for barley and rapeseed.

The tractor emissions from manure spreading were based on a diesel consumption of 25 l/ha, of which 5 l/ha were used for stirring and pumping. The normal application rate was 30 tons slurry per ha, and therefore the application rates used in the scenarios (see Table 3) were assumed to be average rates per year, but for diesel use calculations the rates were aggregated in time to equal 30 tons/spreading event (e.g. approximately every second year).

Electricity use for operation of farm buildings (53 MJ electricity/pig) were taken from Nilsson and Påhlstorp (1985). Processes accounted for, listed in the order of significance, were ventilation, workshops and staff rooms, heating, lighting, manure removal, water pumping and feeding.

4.3 Impact assessment

After the results on energy use and emissions from the SALSA models were obtained, the parameters were related to the functional unit (1 kg pig growth) and classified and characterised into the different environmental impact categories. Equivalency factors for eutrophication and acidification were taken from Lindfors et al. (1995) and for global warming potential (GWP, 100-year time horizon) from IPCC (2001b). For eutrophication, the maximum scenario approach was chosen, where both nitrogen and phosphorous were presumed to contribute to the impact category. Likewise, acidification was assessed by the maximum scenario approach, here also referring to the fact that nitrogen compounds have an acidifying effect in the recipient (Lindfors et al. 1995).

To interpret the total energy consumption behind the energy used in the pig production system, the concept of primary energy was used, where upstream energy use and emissions from production and distribution of fuels and electricity were added to the direct energy use (Rydh et al. 2002). For conversion of diesel consumption to primary energy use, a factor of 1.06 was used. The corresponding figure for Swedish average electricity was 2.1 (after Brännström-Norberg et al. 1996, Arnäs et al. 1997, Uppenberg et al. 2001).

5 Results

5.1 Production of feed ingredients

The energy requirement, contributions to global warming, eutrophication and acidification from the production of each feed ingredient are shown in **Table 6**.

Synthetic amino acids (saa) were distinguished from the other feed ingredients by having substantially higher energy requirement, GWP and acidification potential per kg product. However, saa were used in very small quantities and only noticeably affected energy use in scenario SOY (4%).

In scenario SAA, saa were comparable to peas and rapeseed meal for energy use and acidification.

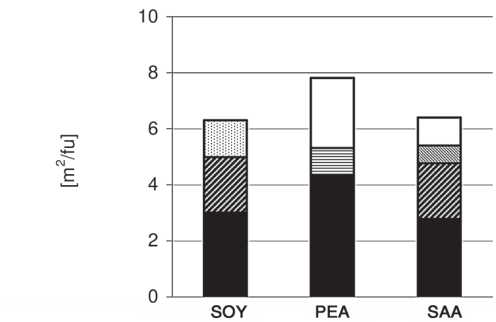
Among the other feed ingredients, of agricultural origin, soymeal had the highest impact for all impact categories. More than half of the energy use and 75% of the acidification were due to long distance transportation. Peas had the lowest energy requirement due to their nitrogen fixing ability, which reduced the need for mineral fertiliser in the crop rotation. On the contrary, peas had a relatively high eutrophication potential. Rapeseed cake contributed least to the emissions of greenhouse gases, which was mainly due to the fact that rapeseed cake is a by-product to rapeseed oil (i.e. 30% allocation). The off-farm extraction and transport caused an additional 50% energy use, 15% GWP, 40% acidification and 2% eutrophication for rapeseed meal, which put rapeseed meal as the second worst agricultural feed ingredient after soymeal, except for eutrophication where peas scored worse than rapeseed meal. The lowest acidification score was shared by wheat and rapeseed cake, and wheat also had the lowest eutrophication. Barley had a relatively low impact for all impact categories.

The area of agricultural land used for feed production per fu in each scenario is shown in **Fig. 2**. Scenario PEA used more land than the other scenarios. The qualitative aspects of land use were not analysed in this study. However, referring to the study of Mattsson et al. (2000), scenario SOY would have a more adverse effect on land use quality than the other two scenarios, due to its inclusion of soybean products.

Table 6: Energy use, contribution to global warming, acidification and eutrophication from production of one kg feed ingredient, as calculated with the SALSA-arable model

Feed ingredient	Energy [MJ]	GWP [kg CO_2-eq]	Acidific. [g SO_2-eq]	Eutrophic. [kg O_2-eq]
Barley[a]	1.45	0.29	1.13	0.11
Wheat[a]	1.34	0.31	0.97	0.10
Pea	1.09	0.31	1.04	0.21
Rapeseed cake[a]	1.57	0.27	0.97	0.12
Rapeseed meal[a]	2.39	0.37	1.67	0.15
Soybean meal	5.02	0.73	8.31	0.42
Synthetic amino acids	86	3.6	41	0.04

[a] Average for the three scenarios



	SOY	PEA	SAA
Soymeal	1.32		
Peas		2.50	1.00
Rapeseed cake		0.97	
Rapeseed meal			0.64
Wheat	1.97		1.99
Barley	3.01	4.34	2.78
Total	6.31	7.82	6.41

Fig. 2: Agricultural land used for production of feed for one kg pig growth for the three feeding scenarios

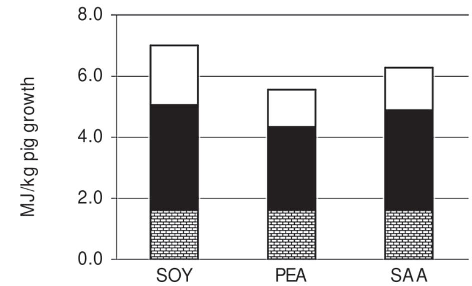
5.2 Production of pigs – The whole system

The feed ingredients were added to the diets in the amounts listed in the feed formulations (see Table 1), which together with the feed production data (see Table 6) determined the total effect from feed production per kg mixed feed. The feed intake was then determined by the metabolisabled energy content of the diet and, in combination with the crude protein content, the nitrogen flow through the pig sub-system could be analysed.

The resulting impacts from both feed production and pig rearing per kg pig growth from each scenario, reported per impact category, are shown in Figs. 3–6.

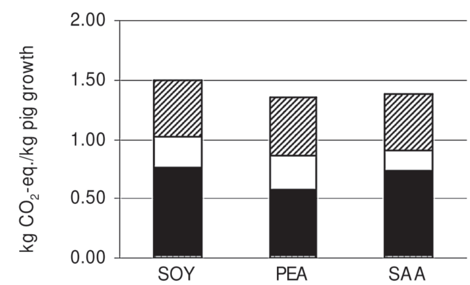
Feed production (energy use and emissions from production of protein feeds and cereals) contributed more than animal husbandry (manure emissions + electricity use for operation of buildings + diesel use for slurry spreading) to the environmental impact of the system for the impact categories energy use, global warming potential and eutrophication, whereas the opposite was the case for acidification. Generally, crops that constituted a large share of the feed's mass (wheat and barley) had a high impact within the feed production sub-system.

Of the energy requirement, 70–76% (depending on scenario) originated from feed production, where field operations were the largest source. In the pig sub-system, energy use for ventilation of the pig building was the most important source (**Fig. 3**). For the contribution to global warming, 60–66% originated from feed production and 34–40% from the pig sub-system. In the feed production sub-system, nitrous oxide emissions from soils constituted the most important source. Manure storage was the source of highest importance in the pig sub-system, mainly through emissions of methane (**Fig. 4**). Note that Swedish electricity production is based on hydro- and nuclear power and thereby generates very little carbon dioxide, compared to many other countries that have a fossil fuel-based electricity production.



	SOY	PEA	SAA
Protein feed	1.94	1.25	1.36
Cereals	3.44	2.71	3.30
Electr&Diesel	1.61	1.62	1.61

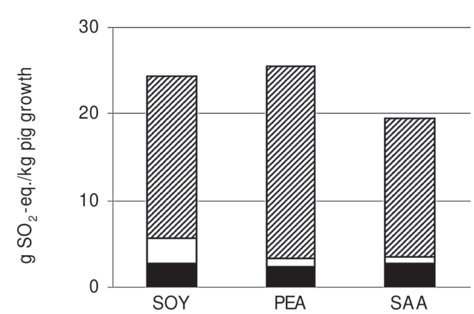
Fig. 3: Energy use per kg pig growth for the three feeding scenarios



	SOY	PEA	SAA
Manure emis	0.48	0.49	0.47
Protein feed	0.26	0.29	0.18
Cereals	0.74	0.55	0.71
Electr&Diesel	0.03	0.03	0.03

Fig. 4: GWP per kg pig growth for the three feeding scenarios

Of the emissions of acidifying substances, 78–88% originated from the pig sub-system, consisting almost entirely of ammonia from animals and manure. Most of the ammonia (59–63%) was released already in the barn. The feed production sub-system contributed the remaining 12–22%, of which combustion of fossil fuels (field operations and transport) was the most important (**Fig. 5**). The emissions of



	SOY	PEA	SAA
Manure emis	18.7	22.2	16.0
Protein feed	2.9	1.0	0.9
Cereals	2.5	2.0	2.4
Electr&Diesel	0.2	0.2	0.2

Fig. 5: Acidification per kg pig growth for the three feeding scenarios

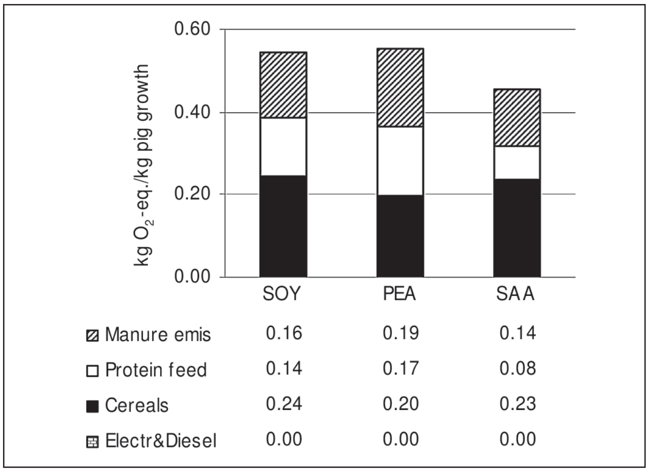


Fig. 6: Eutrophication per kg pig growth for the three feeding scenarios

eutrophying substances were to 66–71% attributable to feed production, where leaching of nitrogen was the most important source. The animal sub-system was responsible for 29–34% through emissions of ammonia (**Fig. 6**).

In order to rank the scenarios, scenario SOY was used as a reference case (p. 154, **Appendix**). The domestic scenario (SAA) managed to reduce the environmental impact for all impact categories analysed compared to scenario SOY, especially for acidification and eutrophication. Scenario PEA scored better on energy use and GWP compared to scenario SOY, but not on acidification and eutrophication.

A sensitivity analysis was performed on the energy requirement per kg weight gain to see the effect of a higher production capacity (**Table 7**). A factor of 31.5 MJ per kg weight gain was used instead of the 35 MJ per kg used in the main study, and this 10% higher efficiency reduced nitrogen excretion by 15%, as a larger share of the incoming nitrogen was used for growth instead of excretion. The effect on the contribution to acidification was a reduction by 20%, as each kg excreted nitrogen saved reduced ammonia emissions in the barn in a second order relationship.

Table 7: Sensitivity analysis of nitrogen excretion and acidification for each scenario as a response to 10% higher feed conversion[a]

Scenario	SOY	PEA	SAA
Nitrogen excretion in relation to the main study	0.85	0.85	0.84
Acidification from the pig sub-system in relation to the main study	0.79	0.80	0.79

[a] The results are outputs from the SALSA-pig model, the feed intake was based on a requirement of 31.5 MJ ME/kg growth

6 Discussion and Interpretation of Results

According to the results in this study, the highest potential for improving the energy use, GWP and eutrophication of the system existed for feed production in contrast to animal management. Avoiding soybean meal, which had a high environmental production cost per kg and formed a relatively high percentage of the feed, reduced the environmental load of the system. Soybean meal can be replaced by peas and rapeseed meal, at least in combination with synthetic amino acids, as was the case in scenario SAA. Replacing a feed based on soybean meal with a feed containing peas, rapeseed meal and synthetic amino acids saved 10% of the energy, 7% of the GWP and 17% of the eutrophication. Even more energy and greenhouse gases could be saved if amino acids were also excluded, as in scenario PEA, but only at the cost of more acidification and eutrophication. Including peas in the crop rotation reduced the need for mineral fertilisers for succeeding crops, in addition to their own nitrogen self-sufficiency. Since production of mineral fertilisers is highly energy demanding and emits large amounts of nitrous oxide (Davis and Haglund 1999), saving mineral fertilisers had a visible effect on the systems' energy use and GWP, as exemplified in scenario PEA.

For contribution to acidification, the highest potential for improving the system existed for the pig-rearing phase, as opposed to the feed production phase. Within the pig sub-system, acidification was caused to 99% by ammonia emissions. There are generally two ways to influence the emissions of ammonia, by reducing the nitrogen excretion and by reducing emissions during manure management. This study shows the effect of feed choice assuming a low-emission technique for manure storage and spreading. Overfeeding with proteins, as in scenario PEA, had a high impact on emissions of ammonia. Despite the low impact from feed production, this scenario lost in the animal sub-system what it had saved in the feed production sub-system. Therefore, it is important to keep levels of crude protein low in pig diets when aiming to reduce acidification from pig production. In this respect, scenario SAA succeeded well, without becoming too low in essential amino acids. This was possible due to the inclusion of synthetic amino acids in the diet, which, despite high production costs per kg product, contributed very little to the total load. However, it should be noted that the uncertainty regarding the environmental impact from production of synthetic lysine and threonine was very high.

The results of scenario SOY in this study were compared to the results in the Swedish study by Carlsson-Kanyama (1998), which analysed a feed containing 6.0% oats, 39% barley, 35% wheat, 10% rapeseed meal, 8% soymeal and 2% peas. The author reported an energy use of 23 MJ and a GWP of 5.2 kg CO_2-eq for production of 1 kg pig meat. Assuming that 1 kg live-weight pig produces 0.73 kg slaughtered carcass with a meat percentage of 57%, 115 kg live pig would give 47.9 kg meat. Furthermore, the sow contributes an additional 1.7 kg pig meat per growing-finishing pig. Since the growing-finishing pig production consumes 60% of the feed in the total pig production system (Rodehutscord et al. 2002), the impact from the whole system could be approximated to 0.60^{-1} times the impact of 86 kg growing-finishing pig growth from the present study. In this context, one kg pig meat from scenario SOY would have an energy use of 19.8 MJ, 4.3 kg CO_2-eq., 70 g SO_2-eq and 1.6 kg O_2-eq. These results can also be compared to the findings of Cederberg and Darelius (2001), where pig meat was reported to have

an energy use of 21.6 MJ/kg, a GWP of 4.8 kg CO_2-eq, an acidification potential of 83 g SO_2-eq and a eutrophication potential of 2.0 kg O_2-eq. The generally lower values of our pig meat can to a certain extent be explained by the piglet production in their study, which consumed more fishmeal and other resource-intensive feedstuffs and more electricity for warming of newborns. In addition, the sows in their study had deep litter straw, which emits much ammonia, and the farm was situated in a part of Sweden with substantially higher leaching of nitrate.

In the work by Canh et al. (1998), diets of 12.5%, 14.5% and 16.5% of crude protein (CP) were tested on growing-finishing pigs. The diet with 12.5% CP did not negatively affect the growth performance of the pigs, while contributing least to the emissions of ammonia. Other studies confirm that a reduced crude protein level of the feed reduces excretion of nitrogen at maintained growth (e.g. Fernández et al. 1999).

The amount of nitrogen excreted by an animal is related to its productive capacity (N retention) and the amount of feed nitrogen intake (Williams 1995). That author discusses various strategies to reduce the nitrogen and phosphorus content of manure. Synthetic amino acids and reduced protein levels in feed were estimated to reduce the nitrogen content in manure by 20–25%, growth-promoting substances (e.g. anabolic agents) by 5%, and phase feeding by 10%. The reduction potential due to reduced protein level is of course dependent on the initial level of protein. As a comparison, the reduction potential for nitrogen excretion was 19% when changing from scenario PEA to scenario SAA, and 10% when changing from scenario SOY to scenario SAA.

The productive capacity of pigs can be enhanced, for example, by genetic progress in feed conversion. Fernández et al. (1999) studied the significance of improving production variables by 10% on the nitrogen excretion of growing pigs. They found that a reduction of dietary protein, increase of growth rate, improvement of feed conversion or improvement of protein utilisation could each reduce N excretion by 13–15%. In the present study some of this was confirmed, as the 10% higher feed conversion tested in the sensitivity analysis reduced nitrogen excretion by 15%, which in turn led to a reduction of the contribution to acidification by 20%. In addition, a 10% higher feed conversion also leads to a 10% lower feed intake. Thus, a higher feed conversion will not only decrease ammonia emissions from the pig, but also reduce the amount of feed needed, with the resulting decrease in environmental impact from feed production.

The results from the eutrophication analysis imply that nutrient leaching from agricultural feed production needs to be controlled in order to keep the total eutrophication low. Soybean and peas both contribute much to eutrophication, and the feed should thus be low in these feedstuffs. Since synthetic amino acids are produced within a factory, eutrophying effluents are fairly easy to control, so the eutrophying performance of the system tolerates a high inclusion of these. Ammonia emissions from the animal subsystem also contribute to the overall result, and should thus be kept low by e.g. low crude protein levels of the feed. The most successful combination of the parameters studied was found in scenario SAA, despite its inclusion of peas.

Kumm (2002) found that the highest reduction potential for nitrate leaching from pig farms is coupled to the spatial location factor, as farms in central Sweden (lower precipitation, clay soils) had only one-third of the leaching level of farms in south-western Sweden (higher precipitation, sandy soils). Besides a relocation of pig farms to interior parts of Sweden, a combination of catch crops, low protein feeding and improved manure handling was suggested as management measures to reduce nitrogen pollution from farms. The spatial location, furthermore, is not only important for the formation of nitrate leaching, but also for the harm caused by the emissions, since different recipients have different sensitivities to additional nitrogen loads. However, the purpose of our study was not to compare farms at different locations, but instead to compare different feeding strategies at a single farm. The local crops in our study were all grown in central Sweden. The most important factor explaining differences in nutrient leaching for different feed ingredients in our study was the crop yield, and, in the case of rapeseed products, also the allocation factor between the co-products rapeseed oil and meal or cake. Based on this, to keep eutrophication low, it is necessary to avoid low-yielding crops in pig diets unless the feed ingredients are by-products to other main products. Eutrophication, however, is a complex issue. From a watershed area perspective it is important to analyse the total land use, and thus also include land not used for pig feed production. If the use of high-yielding crops increased the total production of crops in the watershed area, the eutrophication could increase, although some of this should be debited to other functions than the pig production (e.g. to bread wheat or to biofuel). However, if the higher production efficiency is instead used to set aside some of the agricultural land, a reduction of the eutrophication in the watershed area could arise. Depending on the chosen system boundary, pig production system or watershed area, and on the alternative land use in the latter case, high-yielding crops can be seen as either positive or negative from a eutrophication point of view. The production level within any catchment area should preferably respect the sensitivity of the recipient.

Crop yield per hectare generally had a high impact on the environmental load per kg feed ingredient, as many emissions were more related to the cropped area than to the amount of yield-related inputs (mineral fertilisers, grain drying, etc). A high yielding crop has a low environmental burden per kg product.

Wheat and barley basically fulfil the same function in the diet, supporting the growing pig with metabolic energy. Since wheat had a higher yield than barley, the resulting energy use, acidification and eutrophication per kg cereal were lower for wheat, although the global warming potential was higher. If the first three impact categoriesare more important than GWP, wheat will be preferable to barley as an energy feed for pigs. The relatively high contribution to GWP for wheat

was caused by high rates of mineral fertiliser, which had an effect on both emissions from mineral fertiliser production, nitrous oxide emissions from soils and ammonia emissions from crops and fertiliser application. Even if wheat is the most efficient individual crop, the frequency of wheat in the crop rotation should be adjusted in order to support the overall soil fertility and productivity of the farm.

Clemens and Ahlgrimm (2001) studied measures to reduce greenhouse gases from pig rearing, and state that these may be distinguished as 'preventive' or 'end of pipe' The authors suggest that the best preventive measure is to use highly productive animals fed an optimised diet, while the best measure, once the excreta are already formed, is to use anaerobic digestion plants that collect the methane for fuel purposes and reduce the formation of nitrous oxide due to the anoxic conditions. Low emissions of ammonia in all phases of the production chain will also contribute to a reduced global warming potential, as ammonia gives rise to indirect nitrous oxide formation. Hellebrand and Munack (1995) state that the greatest reduction in agricultural N_2O emissions can be achieved by matching fertiliser application rates to crop requirements.

7 Conclusions

Feed choice had an impact on the environmental performance of pig meat production, not only via the features of the feed as fed to the pigs, such as the crude protein content, but also via the raw materials used, since the environmental impact from the production of these differs and since feed production had a large impact on the system as a whole.

The important factors for a low environmental impact were:

- Exclusion of soybean products from the feed; domestic protein sources had a lower impact on the system
- Low crude protein level of the feed; the use of synthetic amino acids had a positive effect on the system
- Incorporation of peas into the diet and thereby into the crop rotation, as this reduced the need for mineral fertilisers; however, peas were not favourable from a eutrophication perspective and should, furthermore, only be included in the diet up to the threshold where overfeeding with protein starts
- For eutrophication directly related to the pig production system, the use of high yielding crops or byproducts

The systems analysis approach, as exemplified by this study based on the SALSA-models, enabled changes in the two interacting sub-systems (feed production and pig rearing) to be viewed concurrently. Hence, different solutions to problems could be tested and compared for their total system impact.

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Appendix: Environmental impact, per fu, from the three scenarios of pig production including contribution from each source

	Scenario	Feed production						
		Peas	Rapeseed cake	Rapeseed meal	Soymeal	Synthetic amino acid	Barley	Wheat
Energy use [MJ]	SOY	–	–	–	1.67	0.27	1.88	1.55
	PEA	0.65	0.60	–	–	–	2.71	–
	SAA	0.26	–	0.49	–	0.61	1.73	1.57
GWP [kg CO_2-eq.]	SOY	–	–	–	0.24	0.01	0.38	0.36
	PEA	0.19	0.10	–	–	–	0.55	–
	SAA	0.07	–	0.08	–	0.03	0.35	0.36
Acidification [g SO_2-eq.]	SOY	–	–	–	2.76	0.13	1.41	1.10
	PEA	0.63	0.36	–	–	–	2.04	–
	SAA	0.25	–	0.34	–	0.29	1.30	1.11
Eutrophication [kg O_2-eq.]	SOY	–	–	–	0.14	0.00	0.14	0.11
	PEA	0.12	0.04	–	–	–	0.20	–
	SAA	0.05	–	0.03	–	0.00	0.13	0.11

	Scenario	Pig husbandry					Total	Relative diff.
		Manure, excretion	Manure, storage	Manure, spreading	Electricity, building	Tractor for spreading		
Energy use [MJ]	SOY	–	–	–	1.33	0.28	6.83	100%
	PEA	–	–	–	1.33	0.29	5.32	80%
	SAA	–	–	–	1.33	0.29	6.27	90%
GWP [kg CO_2-eq.]	SOY	0.11	0.36	0.01	0.01	0.02	1.47	100%
	PEA	0.12	0.37	0.01	0.01	0.02	1.31	91%
	SAA	0.11	0.36	0.01	0.01	0.02	1.38	93%
Acidification [g SO_2-eq.]	SOY	11.38	3.15	4.17	0.01	0.21	24.3	100%
	PEA	14.00	3.48	4.77	0.01	0.21	25.5	105%
	SAA	9.45	2.88	3.71	0.01	0.21	19.5	80%
Eutrophication [kg O_2-eq.]	SOY	0.10	0.03	0.04	0.00	0.00	0.55	100%
	PEA	0.12	0.03	0.04	0.00	0.00	0.55	102%
	SAA	0.08	0.02	0.03	0.00	0.00	0.45	83%

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Implications of Uncertainty and Variability in the LCA of Pig Production Systems

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Abstract

Goal, Scope and Background. The uncertainty of LCA results stems from the attempt to convert the intra- and inter-system variability of the real world (production systems and natural systems) in LCA data through parameters, models, choices and scenarios. The analysis of LCA uncertainties and their reduction, particularly due to the improvement of the models used to convert emissions into regional impacts such as eutrophication, are two major issues in LCA.

Methods. In a case study of pig production systems, a simple quantification of the uncertainty of LCA results (intra-system variability) is proposed, and the inter-system variability to produce more robust LCA data is explored. The quantification of the intra-system uncertainty takes into account the variability of the technical performance (crop yield, feed efficiency) as well as the emission factors (for NH_3, N_2O and NO_3) and the influence of the functional unit (kg of pig versus hectare used). For farming systems, the inter-system variability is investigated through differentiating the production mode (conventional, quality label, organic) and the farming practices (Good Agricultural Practice versus Over Fertilised), while for natural systems the variability due to physical and climatic characteristics of catchments (expected to modify nitrate fate) is explored.

Results and Conclusion. For the eutrophication and climate change impact categories, the variability of field emissions contributes more to uncertainty than the variability associated with emissions from livestock buildings, with crop yield and with feed efficiency. For acidification, the variability of emissions from livestock buildings is the single, most important contributor to the overall variability. The influence of the functional unit on eutrophication results is very important when comparing systems with different degrees of intensification such as GAP and OA. Concerning the inter-system variability, differences in farming practices have a larger effect on eutrophication than differences between production modes. Finally, the physical characteristics of the catchment and the climate strongly affect the eutrophication results. In conclusion, in this case study, the main sources of uncertainty concern the estimation of emission factors, due to the variability of environmental conditions and due to lack of knowledge (emissions of N_2O at the field level).

Recommendation and Perspective. Suitable deterministic simulation models integrating the main controlling variables (environmental conditions, farming practices, technology) should be used to predict the emissions of a given system as well as their probabilistic distribution allowing the use of stochastic modelling. Finally, the simulations on eutrophication in this study illustrate the necessity of integrating the pollutants fate in models of impact assessment and highlight the need for further research.